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Department of Plant Pathology and Bacteriology

A dangerous combination. This large cedar tree growing in front of the orchard affords ideal conditions for developing an infection of cedar rust.

Experiments on the Control of the Cedar Rust of Apples

BY
HOWARD S. REED, J. S. COOLEY
AND
C. H. CRABILL

IMPERIAL BUREAU OF MYCOLOGY
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†In coöperation with the Office of Tobacco Investigations, Bureau of Plant Industry, United States Department of Agriculture.

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Experiments on the Control of the Cedar Rust of Apples[a]

By Howard S. Reed, J. S. Cooley, and C. H. Crabill

The cedar rust is one of the most virulent apple diseases in the State of Virginia. It is probably safe to say that in the last five years no other fungous disease has produced nearly so much injury to the apple crop. Requests for information on the nature and control of the disease have been numerous. The Department of Plant Pathology has devoted much of its time and energy to work in connection with this problem in the last few years, and experiments of various kinds have been carried out looking toward relief from the inroads of this disease.

The cedar rust of apples is more or less widespread in the eastern and central portions of the United States. It is reported from New Hampshire to North Carolina on the Atlantic seaboard and westward as far as Iowa and Nebraska. The disease is not found except in regions where both apples and red cedars grow. The red cedar is very abundant in most parts of Virginia, and this is undoubtedly one reason why the disease is so abundant in this State. The Shenandoah Valley contains more of the disease than most other portions of Virginia. The principal reason for this condition lies in the fact, that, along with the abundance of cedar trees, the large commercial apple orchards contain many varieties which are particularly susceptible to the disease. Orchards in the vicinity of cedar thickets have usually suffered more severely from the disease than those which are situated at some distance. The injury is more marked if the orchard is on the leeward side of the cedar thickets, where the spores of the disease may be continually borne in by prevailing winds, but all orchards of susceptible varieties of apples suffer more or less severely from the cedar rust.

In 1912, the financial loss to apple growers in this State was estimated to be upwards of one-half million dollars. This, however, did not take into account the loss due to weakening of the trees and to impairing the vitality of the fruit buds for the following year, which would surely diminish each succeeding crop. In any situation where the disease has been severe year after year, the trees have made very small growth, and, on account of their weak condition, have been attacked by numerous other diseases, due to insects

[a]Paper 28 from the laboratories of Plant Pathology and Bacteriology, Virginia Agricultural Experiment Station. (On September 15, 1913, the Department of Bacteriology was combined with that of Plant Pathology. The sub-titles of publications are now adjusted to this change.)

as well as fungi. In many cases, death has ensued before the trees arrived at the bearing age. In some localities the belief has arisen that the York Imperial (*Johnson's Fine Winter*) variety is running out, but it has been shown that the observed injury was simply due to repeated epidemics of the cedar rust disease. Such trees when protected from injury from the disease have resumed their normal growth and produced good crops of apples.

FIG. 1.—York Imperial leaves infected with the cedar rust disease. This appearance is common on diseased trees after July 1st.

SYMPTOMS AND EFFECTS.

The foliage of the tree is the first to be infected with the disease, and it is also the part of the tree which suffers the most. The leaves of susceptible varieties of apples begin to show orange-yellow spots late in May, the time depending naturally upon the season and other conditions to be mentioned later. About one week after these spots appear small pustules (spermagonia) barely visible to the unaided eye may be seen on the upper surface of the leaf. These pustules are yellow at first, but soon become black, and exude a viscid, sweetish substance.

The appearance of these yellow spots is the first sign that the apple leaves are infected with cedar rust. As the season advances the orange-yellow spots increase both in size and numbers, and it is sometimes possible to find 200 on one apple leaf. (Fig. 1.) The leaf in the region of the spot becomes thickened, and if there are many spots the leaf may be rolled upward at the margin as a result of the increased growth on the lower side. After the middle of July the lower surfaces of these cushions are marked with small tubular openings which provide for the discharge of one kind of spore. If the infection is severe, the leaves begin to come off early in August and many times the trees are destitute of leaves by the first of September. Naturally a tree which is deprived of its foliage so early in the season is starving for the food material which the leaf manufactures. As a result of the defoliation and starving, the fruit on such trees is remarkably small, oftentimes being no larger than a crab-apple. The trees make small growth. Sometimes a tree 17 to 20 years old is no larger than normal five-year-old trees.

FIG. 2.—An apple affected with cedar rust. Notice that the cluster cups are near the calyx, showing that infection probably entered through a calyx lobe.

Frequently this disease is apparent upon the fruit, though it is primarily a foliage disease. On the fruit it causes a yellow, puckered spot (Fig. 2), which is frequently studded with tubular openings like those seen on the lower surface of infected leaves. Fruit infection usually is seen at or near the blossom end, because it enters through the calyx lobes while the apple is young and the lobes are still green.

The varieties most susceptible to this disease are: York Imperial, Northern Spy, Rome, Jonathan, and Bonum. The Ben Davis is moderately susceptible, while Winesap, Arkansas (*Mammoth Black Twig*), Stayman Winesap, Northwestern Greening, Grimes, and Yellow Newtown (*Albemarle Pippin*) are distinctly resistant, or even immune.

THE CAUSE OF THE DISEASE.

Cedar rust is caused by a parasitic fungus (*Gymnosporangium juniperi-virginiæ*), which infects the tissue of the apple tree and develops at the expense of the host plant. The fungus which causes this disease has been known to scientists for upwards of forty years, but we have learned much in recent years about the harmful effects of the fungus upon apple trees. The group of rusts to which this fungus belongs contains a large number of species. The red rust and black rust of wheat are among the most familiar species, but there are hundreds all about us forming a great number of diseases upon both wild and cultivated plants. The habit of alternation between different host plants is not peculiar to the cedar rust fungus. The red rust of wheat forms its alternate stage upon plants of the borage family. The black rust of wheat forms its alternate stage upon the leaves of the barberry bush. Others, like the rust of asparagus, produce all stages upon the same plant. In order to have an epidemic of cedar rust, there must, therefore, be present three factors: 1st, red cedars; 2d, cultivated apples; 3d, the fungus.

FIG. 3.—A cedar branch showing numbers of galls, or "Cedar Apples."

The cedar trees in the vicinity of apple orchards usually develop, during the winter and spring, a large number of corky galls, which are commonly spoken of as cedar apples (Fig. 3). These galls contain the teleutospores or winter spores and slowly mature during the warm days of late winter and early spring. Finally, when the weather

becomes warm enough and there is abundant moisture present, such as we are likely to find after a warm rain in April or May, the cedar apples thrust out many yellow gelatinous tendrils (Fig. 4). These jelly masses are often conspicuous for a long distance, and make a unique sight when their number is large. The gelatinous material is composed of the mucilaginous stalks of the teleutospores. When examined with a microscope these yellow tendrils are found to be composed of a more or less transparent ground substance, on which multitudes of minute fungus spores or reproductive bodies are produced. Each of the teleutospores will be found to have germinated and produced four or eight sporidia, which are spores of a different type. So long as the gelatinous material is wet these sporidia do not escape to any extent, but, if bright, sunny days with brisk winds follow, the watery tendrils are dried down and the sporidia are blown away from the cedar apples. The wind, of course, blows these spores where it listeth. Many of them fall in places where they find no suitable conditions for future development and come to naught. Only those which are carried to apple trees find conditions which are suited to their germination and future development.

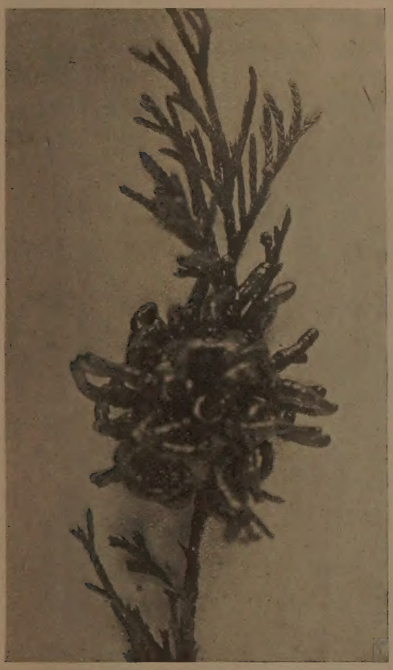

FIG. 4.—A "Cedar Apple" in the gelatinous condition. It is usual to find this condition after a warm, spring rain. When these gelatinous masses begin to dry out they set free millions of sporidia capable of infecting apple foliage.

How far these sporidia may be carried has never been definitely determined. We know that they may travel many miles, and it is probably safe to say that no orchard in Virginia is far enough from cedar trees to be entirely safe from the danger of infection. Our observations and studies go to show, however, that if an orchard is one-half mile from the cedar the amount of rust infection is usually not great enough to be a serious injury to the orchard.

The number of sporidia produced on a single cedar apple is somewhat interesting. The authors have made measurements of the size and number of these sporidia and by calculation found that the sporidia from one average sized cedar apple would, if placed end to end, form a continuous line a mile and one-half long. When we remember that a small sized cedar tree may

FIG. 5.—Slightly enlarged photograph of the lower surface of an infected apple leaf, showing the open "cluster cups" from which the æcidiospores are disseminated.

produce a hundred or more cedar apples, we get some idea of why the cedar rust is such a widespread disease.

If the sporidium has been wafted to the apple orchard there are still necessary three conditions upon which its further development depends:

first, it must be lodged upon the young leaves of a susceptible variety of apple; second, there must be a certain degree of warmth; third, there must be present a small amount of water, which shall be imbibed by the sporidium and start germination. If the season is extremely dry we do not have serious epidemics of this disease, because the third condition is lacking. This was the case in 1911, when some people deluded themselves with the idea that the cedar rust had "petered out." Many of these people were disillusioned

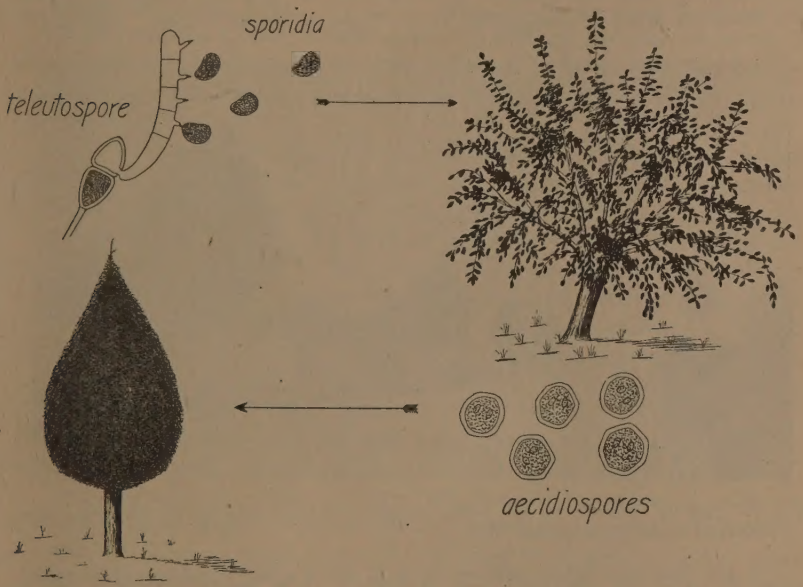

FIG. 6.—The relations of red cedars and apple trees to the cedar rust fungus. The teleutospores produced on the cedars furnish sporidia in the spring which infect the apple foliage. Æcidiospores produced during the summer on the apple foliage reinfect the cedars.

when the moist season of 1912 brought on a memorable epidemic of the disease. The real reason why orchards were so free from cedar rust in 1911 was the fact that very little, if any, rain fell during the time that the sporidia from the cedar tree were capable of germination. Ordinarily, however, there is sufficient rain during the month of May to insure germination of the sporidia. Experiments which we have made show that the sporidia from the cedar tree under ordinary conditions retain their vitality and are capable of infecting apple leaves from one to four days.

About four weeks after the germination of the spores the apple leaves begin to show signs of infection. These appear as small yellow spots on the upper surface of the apple leaf. After a time these yellow spots may be marked with small, black dots. As time goes on the number and size of these yellow spots increase until, in some cases, as we have found by actual count, there may be as many as two hundred on a single apple leaf. The "cluster cups" of the rust develop on these thickened yellow cushions. By the middle of July the yellow spots are considerably thicker than the healthy leaf, and the thickened areas are designated by the name of "Cluster Cups." (Fig. 5.)

FIG. 7.—The red cedar trees are often abundant along roadsides in Virginia. The illustration shows a typical view.

By the first of August another form of spore (the æcidiospore) is ready to be disseminated from the cluster cups on the apple leaf. The æcidiospores are orange colored, and often so abundant that one may obtain them by tapping a leaf on the back of his hand. In such case a fine brown powder would be obtained. (Fig. 6.)

Here again wind is the natural agent for distributing these spores. Enormous numbers of spores are produced, and carried away by every gust of wind. Only those spores have a chance of growing which fall upon leaves of the red cedar (*Juniperus virginiana*). Here they infect the little needle leaf and produce a gall, which becomes a cedar apple and starts again the cycle of disease. It requires about twenty months for the development of a mature cedar apple, hence the infections of one fall will not produce sporidia until a year from the next spring. (Fig. 7.)

SPRAYING EXPERIMENTS.

During the seasons 1911, 1912, and 1913 this department has conducted spraying experiments upon the control of cedar rust in the northwestern part of the State. Orchard trees were kindly placed at our disposal by several parties near Middletown and Strasburg, Virginia. We wish to acknowledge our thanks, especially, to Messrs. Larrick and Larrick, Edgar MacDonald, A. Forney, and J. H. Pifer.

In each orchard a block of trees embracing different varieties was selected. Each block of trees was near enough to cedars to be exposed to considerable chance of infection. In fact the trees were known to have been more or less infected in previous years.

These experiments included the trial of a variety of spray materials, the efficiency of which is herewith discussed. The effect of spraying at various periods of development is treated in a subsequent section.

Lime-sulphur.—The effect of this material has been closely studied for four years. It has been applied in the dilute form as a summer spray. One and a half gallons of the concentrated commercial solution, testing 32 degrees on the Beaumé spindle, was diluted to 50 gallons for use. Arsenate of lead was added to the solution for the early applications. This is the strength ordinarily used in orchard spraying in this State. In the majority of cases this material gave protection against cedar rust, if applied early enough. This material adheres well to the apple leaves and causes a minimum of spray injury.

Iron-lime-sulphur.—This is a spray solution like the preceding with the addition of three pounds of iron sulphate (copperas) to each 50 gallons. The addition of this compound increased the adhesive properties of the spray material. This material when applied to the trees gave the foliage a dark brown aspect. From a distance it appeared as though the leaves had been scorched, but upon close examination no injury could be found. It was possible to find traces of it on the leaves in the autumn at the time of picking the fruit. The efficiency of this spray was quite similar to that of lime-sulphur alone, although in rainy weather it was somewhat greater, due to the fact that it stuck better to the leaves.

Copper-lime-sulphur.—This spray material was made by adding copper sulphate (bluestone) to the ordinary dilute lime-sulphur at the rate of two pounds per 50 gallons.[a] This made a muddy brown spray, due to the forma-

[a]The bluestone was dissolved in three gallons of water, which was then added to the dilute lime-sulphur and stirred in.

tion of copper sulphide, but it was not injurious to the foliage. On most trees, when the copper-lime-sulphur was used, it was possible to find leaves whose margins were much darker green than the normal leaf, but no evidence of scorching by this material was found.

This material gave the greatest protection against cedar rust of any of those tried. The superiority of this spray was especially evident in 1911 in the MacDonald orchard. The sprayed trees showed almost no cedar rust

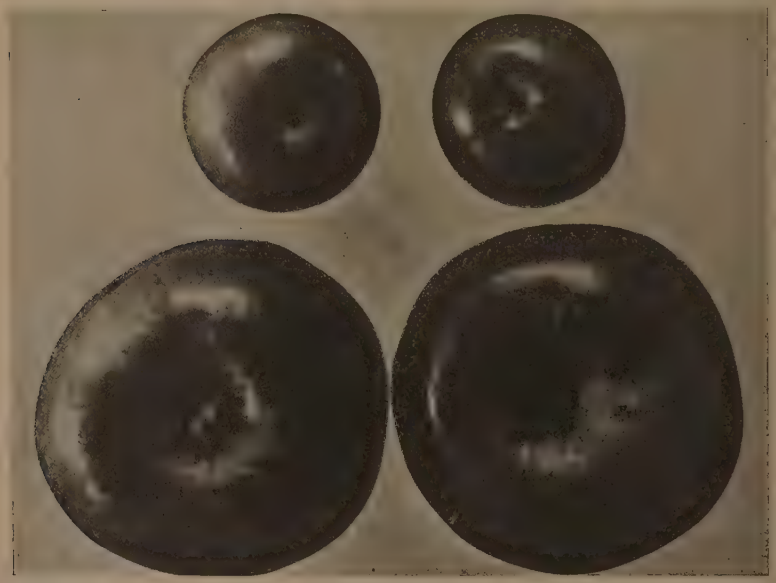

FIG. 8.—The results of spraying York Imperial with copper-lime-sulphur. The two lower apples came from a sprayed tree; the two upper came from an unsprayed tree in the next row.

infection, averaging only three spots per leaf; while the unsprayed trees had an average of 111 spots per leaf. (See table II.) The effect of this spray material upon the size and quality of the fruit is shown in Fig. 8. In 1912, this material did not give quite as good results, due, probably, to the fact that hard rains washed it off too soon. This difficulty was overcome in 1913 by the addition of one-half gallon of "black strap" molasses to each 50 gallons of spray material.

Atomic Sulphur.—This is a trade preparation which was claimed to have especial value in controlling cedar rust. It is sold in the form of a paste, which appears to be very finely ground sulphur, and when required for use is mixed with water at the rate of 10 pounds to 50 gallons of the latter. This material appears to have about the same value for the control of cedar rust as ordinary lime-sulphur, but it did not adhere to the foliage as long. After two years' experiment we did not find it enough better for this purpose than ordinary lime-sulphur solution to warrant the higher price charged for it.

Bordeaux Mixture.—This material was made of 3 pounds copper sulphate (bluestone), 4 pounds unslaked (stone) lime, and 50 gallons water, and applied as soon as made.

During the past few years nearly all of the apple growers in this State have discarded Bordeaux mixture for the dilute lime-sulphur solution, because of the freedom from spray injury when the latter is used. However, Bordeaux mixture is still the standard spray for control of the bitter rot of apples. The fruit of such varieties as Ben Davis, Arkansas (*Mammoth Black Twig*), Jonathan, Baldwin, and Gano usually suffer quite extensive russeting of the skin when sprayed during their early stages with Bordeaux mixture. On the foliage various types of injury, such as spotting, curl, or scald may be produced. These types of spray injury and their causes have been discussed in former publications[a] and need not be repeated here. Injury from spotting the leaves was quite common on the Bordeaux plat of our experiments in 1913.

Bordeaux mixture has, nevertheless, always shown itself it be exceedingly effective in controlling cedar rust. Wherever copper compounds are present in the spray mixture they appear to give noticeable protection against the cedar rust. This may be in part due to the fact that sprays like Bordeaux and copper-lime-sulphur have good adhesive powers, but we do not believe that all the benefit can be accounted for in that way.

In our experiments in 1910 and again in 1912 we found from 5 to 10 per cent less rust on trees sprayed with Bordeaux mixture than on those sprayed with lime-sulphur. Yet on account of the danger from spray injury we do not recommend Bordeaux mixture for the control of cedar rust.

Iron Bordeaux Mixture.—This is the regular 3-4-50 Bordeaux mixture to which 3 pounds of iron sulphate (copperas) were added. This gave the mixture a brown color which was very noticeable on the foliage of the trees. The addition of the iron sulphate increased the adhesive property of the mixture, but did not alter the question of spray injury. This formula for

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[a]Foliage Diseases of the Apple, Bulletin 195, Virginia Agr. Exp. Sta., 1912. Spray Injury, Annual Rep't Virginia Hort. Society, 1911.

Iron Bordeaux seems to have been first used by Selby of the Ohio Agricultural Experiment Station and has also been tried by Waite.[a] This material has practically the same efficiency in controlling cedar rust as the regular Bordeaux, although at times we have found that its better adhering properties have made it slightly more efficient.

In 1912, we found that the use of Bordeaux and Iron Bordeaux caused some spray injury on the apple leaves. This injury was manifested only on those leaves which were young at the time of spraying, and later showed infection with the rust fungus. It seems probable that rust infection had taken place just before the sprays were applied, and that the dissolved copper entered the leaves through the openings which the fungus hyphæ had made. These leaves showed very slight spray injury soon after they were sprayed, and about June 28th they began to turn yellow. On July 3d one to three leaves had fallen from many twigs.

Mercuric Bichloride.—This material was tried in the experiments one year with fairly good success. It is a substance having great germicidal powers and consequently much used as a disinfectant in surgery. We sprayed York apple trees with a solution containing one part of the mercuric bichloride in a thousand of water without injury to the foliage, but with good results in diminishing the amount of cedar rust. It must be stated, however, that the season was marked by scanty rainfall, and that the amount of infection was small, and also there was little chance for this material to be washed from the foliage. The trees on which the spray material was applied were without a crop of fruit, consequently no observations upon spray injury on the fruit could be made. It is not assumed that the use of mercuric bichloride is practical in a commercial way.

THE AMOUNT OF CEDAR RUST INFECTION UPON APPLE TWIGS.

The following data show the effect of certain sprays in controlling cedar rust upon some of our experimental trees in 1911, and also show the periods at which infection was most severe.

The data were obtained by counting the number of rust spots on leaves of the current season's growth, that is, on the summer wood only. These twigs offered a series of leaves the first of which appeared as soon as the tree began growth in the spring, and unfolded in succession until about June 25th, thus covering the time during which infection can take place.

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[a] Experiments on the apple with some new and little known fungicides, Circular 58, Bureau of Plant Industry, U. S. Dep't of Agr., 1910.

The data given in table I show the method of counting the infections, as well as the distribution of the same on the leaves of that year's growth.

TABLE I.

Number and Distribution of Cedar Rust Infections Upon an Unsprayed York Imperial Apple Tree. MacDonald Orchard.

	Number of cedar rust infections upon leaves in serial order.																		
Leaf No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Total
Twig I	1	0	0	0	0	0	0	0	0	0	0	0	13	34	30	16	30	7	0	131
Twig II	0	0	0	0	0	0	0	0	0	20	12	28	42	11	1	0	0	0	0	114
Twig III	0	0	0	0	0	0	0	0	1	5	17	36	24	28	3	0	0	0	0	114
Twig IV	0	0	0	0	0	0	0	1	1	15	13	34	6	0	0	0	0	0	0	70
Twig V	1	0	0	0	0	0	0	0	0	1	29	20	4	26	16	0	0	0	0	97
Twig VI	1	0	0	0	0	0	0	0	1	23	39	40	22	14	0	0	0	0	0	140
Total	3	0	0	0	0	0	0	1	3	64	110	158	111	113	50	16	30	7	0	666

The figures show very strikingly the fact that apple leaves are only susceptible to infection with cedar rust during their early stages. The first nine leaves on these twigs are shown to have only seven of the 666 infections produced by the fungus. By the time the maximum infection was taking place these early leaves were beyond the susceptible period and escaped infection.

Since this was an unsprayed tree, it cannot be claimed that subsequent applications of spray material had any influence upon these results.

During the month of May no rain fell and consequently no sporidia were produced upon the cedar apples. This accounts for the very small amount of infection upon the first nine leaves of the twigs. The sudden rise when the tenth leaf is reached is due to the fact that rain fell on the evening of May 31st and caused the cedar apples to put forth an abundance of gelatinous tentacles on which a large crop of sporidia were produced on the ensuing day. It was this crop of sporidia which caused the infection of leaves 10 to 15 shown in table I.

It will be noted that six leaves (numbers 10 to 15, inclusive) received the most of the infection of that year. These were leaves which appeared just prior to the heavy infection on the first days of June.

This method of counting was also used to estimate the relative efficiency of different sprays in controlling cedar rust on our experimental trees. The data from trees in different experiment plats is summarized and presented in table II. The Roman numerals in the third column of the table refer to the applications of spray material given.

Application I was made on April 26th when the cluster buds on Yorks were well unfolded, but lateral buds were still closed. About three days later the blossoms began to unfold and a week later the trees were in full bloom. Application II was made, on May 16th, about a week after the bloom dropped, when the trees had a good covering of leaves, many of which were full size. Application III was made on June 1st and was really the most important application for that season, because the heaviest infection began on the day on which the spray material was applied.

TABLE II.

Number of Cedar Rust Infections Upon Leaves of York Imperial Apple Trees on Different Plats in the MacDonald Orchard, 1911.

Tree No.	Spray applied.	Applications given	Average number of infections per twig of the season's growth.
12	None		111
63	None		115
112	Lime-sulphur	I, II, III	55
200	Lime-sulphur	I, II	94
62	Atomic sulphur	I, II, III	82
13	Copper-lime-sulphur	I, II, III	3
10	Copper-lime-sulphur	I, II, III	2
65	Bordeaux mixture	I, II, III	37
51	Bordeaux mixture	I, II, III	43
40	Iron Bordeaux	I, II, III	41
32	Iron Bordeaux	I, II, III	52

These figures were all obtained by the method used in preparing table I, and show that some of the spray treatments had great value in controlling the cedar rust on the experimental trees. In the work of 1912 and 1913, the lime-sulphur spray gave somewhat better results than the figures in the above table would show, but the other spray materials show much the same. If application II had been made a few days earlier it is possible that the number of rust infections on all would have been somewhat smaller.

As stated above the use of copper-lime-sulphur gave remarkable freedom from infection even when applied on the same day as the other materials.

LABORATORY STUDIES UPON THE EFFECT OF SPRAY MATERIALS ON THE GERMINATION OF SPORIDIA.

During the past three years the germination of cedar rust sporidia in the presence of various spray materials has been tested by a method described by Wallace.[a]

The following sprays were made up in small quantities in the laboratory: 4-5-50 Bordeaux Mixture; Iron Bordeaux, made by adding 3 pounds of iron sulphate to 50 gallons of 4-5-50 Bordeaux; Pyrox, 1 pound to 6 gallons of water; Lime-sulphur, 1½ gallons to 50 gallons of water; Copper-lime-sulphur, made by adding 2 pounds of copper sulphate to 50 gallons of 1½ to 50 lime-sulphur; Atomic Sulphur, 1 to 10; and Sulfocide, 1 gallon to 200 gallons of water.

Small glass slides were sprayed or otherwise coated with the spray materials, held up to allow all excess of spray to drain off, and then allowed to dry. Cedar rust sporidia were then obtained from gelatinous or drying cedar apples and mixed with a small quantity of water. A few drops of the suspension thus obtained were placed on each of the sprayed slides and also on some unsprayed slides which acted as controls. The slides were then placed in a moist chamber to await the germination of the spores. After 48 hours they were examined under the microscope and the percentage of germination determined. The results of these tests are incorporated in table III.

TABLE III.

Effect of Different Spray Materials Upon the Germination of Sporidia.

Spray material tested.	Number of tests made.	Average per cent of spores germinating.
Bordeaux mixture	8	1.1%
Iron bordeaux	5	2.8%
Pyrox	3	0.0%
Lime-sulphur	7	1.5%
Copper-lime-sulphur	5	2.8%
Atomic sulphur	3	3.2%
Sulfocide	3	0.0%
Controls (unsprayed)	8	52.3%

An examination of this table will show that all of the sprays used are very efficient in preventing the germination of rust spores. Bordeaux Mixture,

[a]Studies of the fungicidal value of lime-sulphur preparations, Bull. 290, Cornell Agr. Exp. Sta., 1911.

Iron Bordeaux, and Pyrox completely extracted the color from rust spores in 24 to 48 hours, in addition to almost entirely prohibiting germination in all cases. Lime-sulphur, Copper-lime-sulphur, Atomic Sulphur, and Sulfocide did not decolorize the spores, but killed them nevertheless. On the unsprayed slides the spores germinated in much larger numbers, as will be seen by examining the figures under the heading "Controls."

The Timeliness of the Applications.

Much of the work presented in the foregoing pages shows that timeliness of spraying is a very important factor in preventing infection with the cedar rust.

In table II, it is shown that tree No. 200, which received the first and second lime-sulphur sprayings, had an average of 94 cedar rust infections on that season's growth; while tree No. 112, which received all three applications, had but 55 infections.

This was because the third spraying was made on June 1st, the day on which the largest crop of sporidia of that year was beginning to be disseminated. That this was the most important spraying of that year is shown by the fact that there were nearly as many infections on the tree sprayed with applications I and II as on the unsprayed trees.

In 1913, we waited until after the trees had shed most of their blossoms before making any application of spray materials. At that time the oldest leaves on the York Imperial trees were only about half their normal size, but, on account of their tender condition (lack of thick cuticle, turgidity, etc.), were in an especially favorable condition for infection. The first application of spray materials was made on April 29th, and was followed by a second on May 12th, and a third on June 2d. Rains from the 11th to 15th of April had made the cedar apples gelatinous and produced a large crop of sporidia which were disseminated from the 15th to 18th, but caused no infection because the apple foliage had not then appeared. There was a slight rain on April 26th and 27th after which the tentacles on the cedar apples were extruded slightly, but apparently few sporidia were produced and little infection of apple leaves followed. On May 14th and 15th there were showers and on the 17th rain fell nearly all day. As a result the cedar apples were discharging many sporidia when it cleared up on the 18th. The weather was then bright and warm for several days, gradually drying out the cedar apples and allowing the sporidia to be disseminated by winds. The maximum dissemination of spores in 1913 took place on May 19th and 20th. Rains on

the 26th and 27th of May brought forth another smaller crop of sporidia which were disseminated on the 28th. After that date there were not many sporidia produced and little infection of apple leaves followed.

The general conditions of the cedars, the apples, and other factors are summarized and set forth in table IV.

TABLE IV. *Summary of Factors Influencing Cedar Rust Infection in April, 1913.*

			1	2	3	4	5
Weather			Fair	Fair	Fair	Fair	Fair
Condition of Cedar Apples			Undeveloped				
Spore Dissemination			None				
Condition of Apple Trees			Dormant				
Spraying							
	6	7	8	9	10	11	12
Weather	Fair	Fair	Fair	Fair	Slight rain	Rain	Rain
Condition of Cedar Apples						Slightly gelatinous	Highly gelatinous
Spore Dissemination							
Condition of Apple Trees							
Spraying							
	13	14	15	16	17	18	19
Weather	Cloudy and damp	Cloudy and damp	Cloudy and rain	Fair	Fair	Slight rain	Fair
Condition of Cedar Apples	Highly gelatinous	Highly gelatinous	Highly gelatinous	Drying rapidly	Almost dry	Dry	Dry
Spore Dissemination				Great	Very great	Moderate	Slight
Condition of Apple Trees			Cluster buds swelling			Few cluster leaves open	Cluster leaves open
Spraying							
	20	21	22	23	24	25	26
Weather	Fair	Fair	Fair	Fair	Fair	Fair	Very slight rain
Condition of Cedar Apples	Dry						Dry
Spore Dissemination	Almost ceased						
Condition of Apple Trees	Cluster leaves open	Full bloom	Full bloom	Full bloom	Full bloom	Petals falling	Petals falling
Spraying							
	27	28	29	30			
Weather	Very slight rain	Fair	Fair	Fair			
Condition of Cedar Apples	Dry						
Spore Dissemination							
Condition of Apple Trees	Petals falling	1-3 twig leaves open	Petals fallen				
Spraying			First spray applied				

TABLE IV (*Continued*). *Summary of Factors Influencing Cedar Rust Infection in May, 1913.*

					1	2	3
Weather					Fair	Fair	Fair
Condition of Cedar Apples					Dry		
Spore Dissemination							
Condition of Apple Trees							
Spraying							
	4	5	6	7	8	9	10
Weather	Fair	Fair	Fair	Fair	Fair	Fair	Fair
Condition of Cedar Apples							
Spore Dissemination							
Condition of Apple Trees							
Spraying							
	11	12	13	14	15	16	17
Weather	Fair	Fair	Fair	Rain	Rain	Slight shower	Rain and cloudy
Condition of Cedar Apples				Highly gelatinous	Highly gelatinous	Drying rapidly	Gelatinous
Spore Dissemination						Great	Slight
Condition of Apple Trees		4-5 twig leaves unfolded				3-7 twig leaves open	
Spraying		Second spray applied					
	18	19	20	21	22	23	24
Weather	Fair	Fair	Cloudy	Cloudy	Fair	Rain	Cloudy
Condition of Cedar Apples	Drying	Almost dry	Dry	Dry	Dry	Gelatinous	Gelatinous or drying
Spore Dissemination	Great	Great	Great	Slight	Almost ceased		Moderate
Condition of Apple Trees							
Spraying							
	25	26	27	28	29	30	31
Weather	Fair	Slight shower	Rain	Fair	Fair	Fair	Fair
Condition of Cedar Apples	Dry	Dry	Slightly gelatinous	Drying	Dry	Dry	Dry
Spore Dissemination	Almost none	Almost none		Slight (sori exhausted)			
Condition of Apple Trees						7-9 twig leaves open	
Spraying							

With a knowledge of these conditions it is evident that the spray material applied shortly before the dissemination of large numbers of sporidia was of most value in preventing infection. The spray application made on April 29th protected the leaves unfolded at that time until the second application was made on May 12th, when many more leaves had developed which were of course unprotected by the first spray. This second spray was highly important, because it protected all foliage formed before May 12th from the extensive infection of May 19th and 20th. The third spraying was designed to protect the foliage during the remainder of the time during which infection was possible.

York Imperial trees which were sprayed a few days before rust infection took place had crops of first-class fruit, while trees which were sprayed a few days too late had nothing but small, inferior fruit.

The results of our work, therefore, indicate that spraying is effective in controlling the cedar rust, provided the spray material is applied at the right time.

The chief difficulty in controlling this disease lies in the fact that the time of greatest infection (and, therefore, the proper time to spray) is entirely dependent upon weather conditions and varies somewhat with the season. For example, in 1911 the month of May was marked by a drought in Frederick County, and no severe rust infection took place until June 5th. The season of 1912, however, had a more normal rainfall, and a severe infection of cedar rust occurred May 7th to 9th. If the young apple leaves can be coated with spray material soon after they unfold, and kept coated until the first week in June, spraying will be effective in controlling this disease.[a] It is especially important that the first spraying be applied as soon as possible after the blossoms have fallen. In fact the first application may be made while there are yet some blossoms on the tree. The few belated blossoms which sometimes appear may be disregarded.

The objection may be raised that it is detrimental to bees and other beneficial insects to spray while the trees are in bloom. We do not advocate spraying while the trees are in full bloom, but rather spraying as early as possible after the blooming period is over. The fruit is set and the bees cease to visit the flowers while some petals still cling to the trees. One can, therefore, spray with safety even when the trees are shedding the last of their blossoms. In the case of varieties like the Jonathan, which unfold their foliage quite early, it may even be advisable to spray before the trees blossom, but in the case of varieties like York Imperial this would not be practical.

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[a]Our experience in this matter is corroborated by others. Compare—Bartholomew, Phytopathology, 2 : 253, 1912; Giddings and Neal, Phytopathology, 2 : 258, 1912.

ERADICATION OF THE CEDAR TREES.

The foregoing discussions have attempted to show that the red cedar (*Juniperus virginiana*) is an indispensable factor in the propagation of the cedar rust disease.

Briefly the facts in the case are as follows:

1. Orchards in close proximity to cedar thickets have been the worst sufferers from this disease, especially if the direction of the prevailing winds was such that sporidia were readily carried to the orchard from the cedars. Orchards situated remote from the cedars escape serious infection although they contain susceptible varieties of apples.

2. The removal of the cedar trees from the vicinity of orchards has in all cases known to the writers brought permanent relief from this disease.

3. Inoculation experiments show that cedar rust is only developed from the cedar apples.

In 1912, several small York Imperial apple trees were planted and carefully covered with large glass bell jars to prevent spores of any fungus from reaching them. One portion of the trees were inoculated by spraying a suspension of sporidia in water on the leaves with an atomizer; another set were inoculated by hanging gelatinous cedar apples in the bell jars; the others were not inoculated. The first set of trees developed a few rust infections, the second had numerous typical infections, while the third had none and remained free from rust during the entire season.

Subsequent publications will give detailed proof of the necessity of the red cedar in the life cycle of this fungous disease, but space forbids an adequate discussion of the experiments in the present article.

For several years this department of the Experiment Station has been advising apple growers to destroy the cedar trees in localities where the cedar rust has been troublesome. Some were at first skeptical of the value of such advice, but those who followed it have been convinced that the cedar tree was responsible for one stage in the propagation of this disease, because the apple orchard has been so strikingly benefited when the cedars were removed.

In this connection it seems proper to introduce extracts from two letters recently received discussing the benefits experienced from cutting cedars:

FISHERSVILLE, VIRGINIA,
November 4, 1913.

MR. H. S. REED,
Blacksburg, Va.

DEAR SIR:— . . . I was not convinced of the cedar rust for several years. In the year 1912 I was thoroughly convinced. I had a heavy crop of apples. My trees

were full, but I don't think I had as much as one barrel that would have done to pack, as none of them were larger than a hen's egg. My apples were of no use except for cider.

In the winter I cut down the cedars on my place. This year I found some cedar rust on my apples, but not very much. I had a very nice crop of apples this year. I made dollars on my apples this year where I lost dollars last year on account of the cedar rust. I would advise any one who has a cedar on his place to cut it down, as it does lots of damage to an orchard.

Respectfully yours,

(Signed) DANIEL THACKER,
Fishersville, Va.

MIDDLETOWN, VIRGINIA,
October 24, 1913.

MR. H. S. REED,
Blacksburg, Va.

DEAR SIR:— . . . The cedar rust so affected the fruit and foliage of the Yorks that we had no apples fit to put into barrels. A great many trees affected would shed their foliage prematurely. The Ben Davis foliage was not affected, but the fruit was so splotched with cedar rust that at least twenty-five per cent had to be packed as No. 2 which would have been No. 1 except for the rust. We saw that we were up against a great proposition, as we had been to heavy expense in planting, spraying, and cultivating the orchard up to the age when we had hoped to reap some benefit from our labor and expense for twelve years. . . . Word went out from the Experiment Station that the only thing to cure or prevent cedar rust was to cut the cedars within at least half a mile of the orchard. . . . We cut all the cedars east and southeast of us. . . . The first crop of York apples we had after cutting the cedars was the first we had gotten from our orchard fit to put into a barrel. We must say they were very fine. . . . North of us is a piece of timber land which is full of cedar trees. It belongs to a man who cannot be convinced that the cedar tree is the cause of cedar rust. We cannot get at these trees. Here is where we found most of the cedar rust this year. If we could get the cedars cut back in this piece of timber 100 yards from our orchard we are satisfied we would have the cedar rust about conquered in our orchard.

We are sorry we cannot give you an estimate of the amount we have lost by cedar rust. We find our bank account has increased since we cut the cedars.

Yours very truly,

(Signed) LARRICK AND LARRICK.

These letters show that there is but one verdict on the question of destroying the cedar trees, viz.: that relief from the cedar rust is obtained.

FIG. 9.—The effect of cedar rust from neighboring cedars. This York Imperial tree has lost most of its foliage.

FIG. 10.—Tree in same orchard as that shown in Fig. 9, but located far enough from cedar trees to escape severe infection. Note the healthy condition of the foliage.

Experiments made at Middletown by one of the authors show that the cedar galls will retain sufficient vitality to produce sporidia and serve as a source of infection to the orchards for two months after the trees are cut down. Therefore it is advisable to burn any trees cut after March first.

Since it is the fungous spores coming from the cedar apples which cause the disease, the cedar trees may be rendered nearly harmless by picking off these growths and burning them. This practice might be followed in the case of a few ornamental trees near the homestead which the owner would be loath to destroy. This means that the trees should be carefully examined and all cedar apples picked by hand before March of each year.

WHAT IS THE STATUS OF THE CEDAR TREE?

The question has often been asked, "Shall we not regard the red cedar tree as a universal pest?" When we review the situation in Virginia it must be admitted that in some sections the cedar rust disease has done as much harm as San José scale or Black Knot. The proposal has frequently been made to list the red cedar as a pest, and to seek legislation empowering its destruction where it is a menace to orchards. Some such measure would undoubtedly be desirable in cases where apple growers suffer from infection coming from neighboring farms, especially from farms on which apples are not grown commercially. Many instances are known in which the owner of cedars has refused to cut, or even to sell the privilege of cutting cedar trees which are of no commercial value whatever. Often the cedars are mere bushes growing in fence corners or on barren hillsides where they would never grow large enough to be used as timber, or posts; however, these same bushes may produce enough infective material to spread disease to many acres of orchard and destroy thousands of dollars worth of apples. This is undoubtedly an unjust state of affairs.

On the other hand there is something to be said for the owners of some cedar trees. Often these trees have been reared for many years as ornaments on home premises, in cemeteries, as wind breaks, etc., and have a real value to the owners. Obviously, if such trees are destroyed the owners should be reimbursed. Moreover, there are many portions of the State in which apple growing is not a commercial enterprise, and there are others in which few, if any, susceptible varieties of apples are grown, where it might rightly be maintained that the cedar is not a pest.

It cannot be denied, however, that in recent years the loss to the State from this disease has amounted to a far greater sum than the value of the neighboring cedars, and that a measure bringing suitable relief would be most welcome in many quarters.

In the meantime, in the absence of legislation, much might be done to alleviate the trouble by coöperation among apple growers to educate the general public upon this question and to create a sentiment in favor of checking this disease. It ought certainly be the desire of every one to increase the general prosperity of his community in this way. County horticultural societies and local farmers' clubs can well afford to discuss the control of this disease, and to persuade their members to do whatever seems wise to stop the loss from cedar rust. If property owners desire to plant ornamental evergreens, spruce or white pine may be substituted for the obnoxious cedar with perfect safety.

FIG. 11.—This cedar tree by the roadside is a source of infective material for the orchard opposite.

SUMMARY.

1. Cedar rust has come to be one of the most serious fungous diseases of the apple in many portions of Virginia. The foliage of the tree is seriously affected by the disease, resulting in great injury to the trees and fruit.

2. The cause of the disease is a fungus known scientifically as *Gymnosporangium juniperi-virginianæ,* which lives as an alternating parasite upon

red cedars and apple trees. Sporidia produced upon the cedar in early spring are carried by winds and cause the infection of the apple foliage. Æcidiospores from diseased apple leaves will, if lodged upon cedar trees, infect them and produce in about twenty months mature "cedar apples."

3. The time and amount of infection of apple foliage is very largely dependent upon climatic conditions. An alternation of rains and fair weather is most favorable for heavy infection, and a resulting epidemic of cedar rust.

The apple leaf is only susceptible to infection with cedar rust during the early period of its development.

Older leaves may be considered to be immune to this disease. The foliage of different varieties of apples shows considerable variation in susceptibility to the disease; certain varieties, like Winesap, Arkansas, Stayman Winesap, Northwestern Greening, Grimes, and Yellow Newtown (*Albemarle Pippin*), being practically immune; while others, notably York Imperial, Northern Spy, Rome, Jonathan, and Bonum, are very susceptible.

4. The experiments made show that certain spray materials have great value in controlling cedar rust in the orchard. Copper-lime-sulphur, a new spray, has shown great efficiency as a preventive of the disease. Ordinary lime-sulphur and Bordeaux mixture are also good.

5. The time of the application is of more importance than the kind of spray material used. Spraying should begin shortly after the young leaves unfold and be repeated often enough to protect the foliage appearing up to the 10th of June. In some cases it is desirable to spray before the trees bloom, in the others spraying should begin at the first possible moment after the blooming period is over.

6. Since the time for effective spraying is so limited it is generally impossible to spray all the trees in a large orchard at the proper time, and it is far more practical to remove the source of infection, viz., the cedar trees. Destruction of all cedar trees within a half mile of the orchard will prevent serious epidemics of cedar rust, although a small amount of infection may be borne from almost any distance. Unmistakable benefits have been experienced wherever cedar thickets in the vicinity of orchards have been destroyed. In many localities this seems to be the cheapest and most effectual method of handling the disease. Any cedar trees which are cut after March first should be burned, since they retain the ability to cause infection for two months.